Dark Sectors+Real-Time Processing @ LHCb
&
AI for Scientific Discovery

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LHCb if painted by Van Gogh according to a Deep Neural Network.

My Group Members

Mike Williams
Professor
Group Leader (ie useless)
IAIFI Deputy Director

Adrian Casais Vidal
Post-doc
Real-time processing
Dark Sectors

Blaise Delaney
Post-doc
Real-time processing
CP violation

Ouail Kitouni
PhD Student
AI robustness
Representation Learning
(Currently at Meta AI)

Kate Richardson
PhD Student
Real-time processing
Dark photons

Looking for new PhD students!

My Former PhD Students

- Constantin Weisser, PhD 2021: First recipient of the **PhD in Physics, Statistics, & Data Science**. He did a short fellowship at NASA before starting his current position as a **Data Scientist** at Quantum Black.

- Tom Boettcher, PhD 2021: Won the LHCb Thesis Prize and is now a **postdoc on LHCb** at the University of Cincinnati.

- Yunjie Yang, PhD 2021: Started as a post-doc at the NY Proton Center and is now a **medical physics resident** there.

- John Hardin, PhD 2018: Did a **winter-over at the South Pole** working on IceCube, and is now a post-doc in Janet Conrad's group here at MIT.
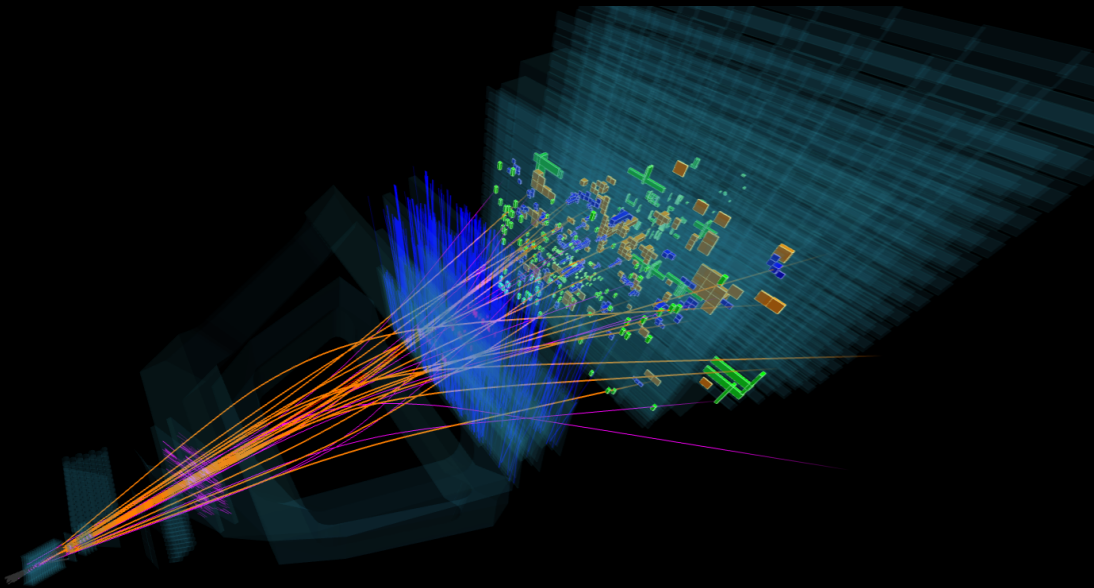
Former LHCb Post-Docs

- Niklas Nolte, 2021-2023: Now working at Meta AI.

- Arthur Hennequin, 2022-2023: Now a CERN Fellow.

- Dan Johnson, 2021-2023: Now faculty at the University of Birmingham, England.

- Dan Craik, 2017-2022: Now an Ambizione Fellow at the University of Zurich.

- Phil ilten, 2013-2017: Now a tenured professor at the University of Cincinnati working on LHCb.
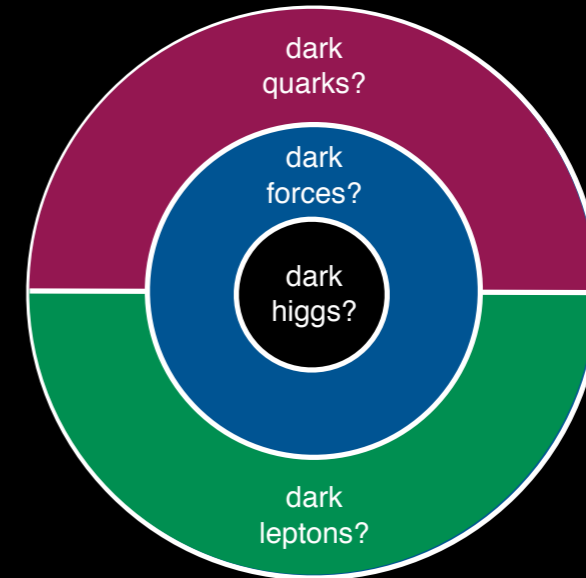
Group Overview

We primarily work on the 3 main topics below, though we also do some work on QCD physics, etc.
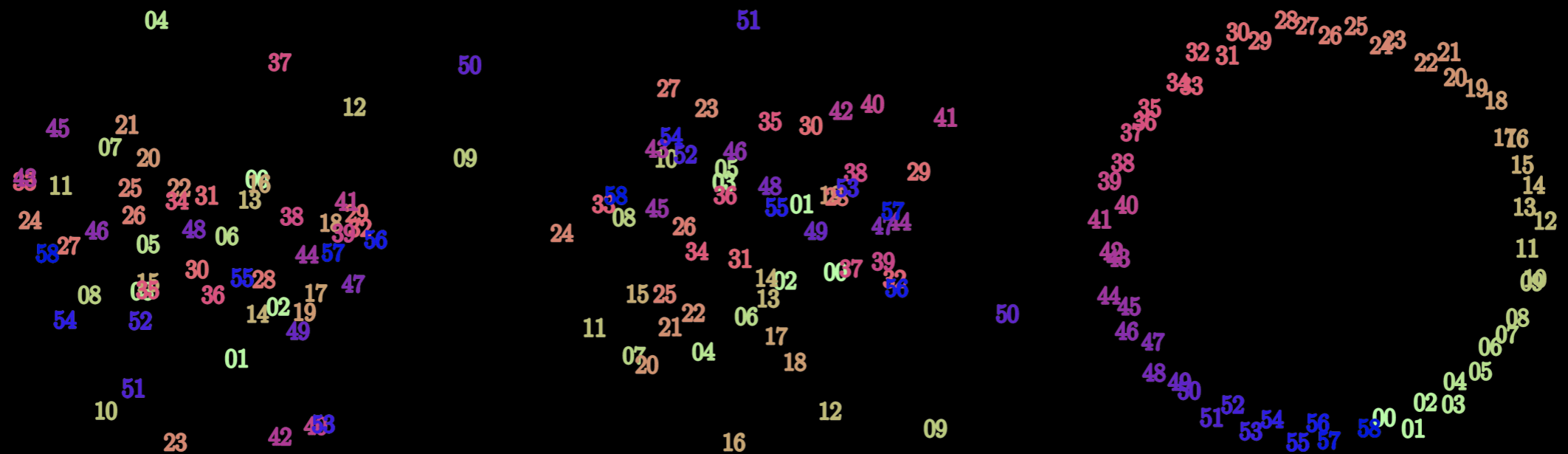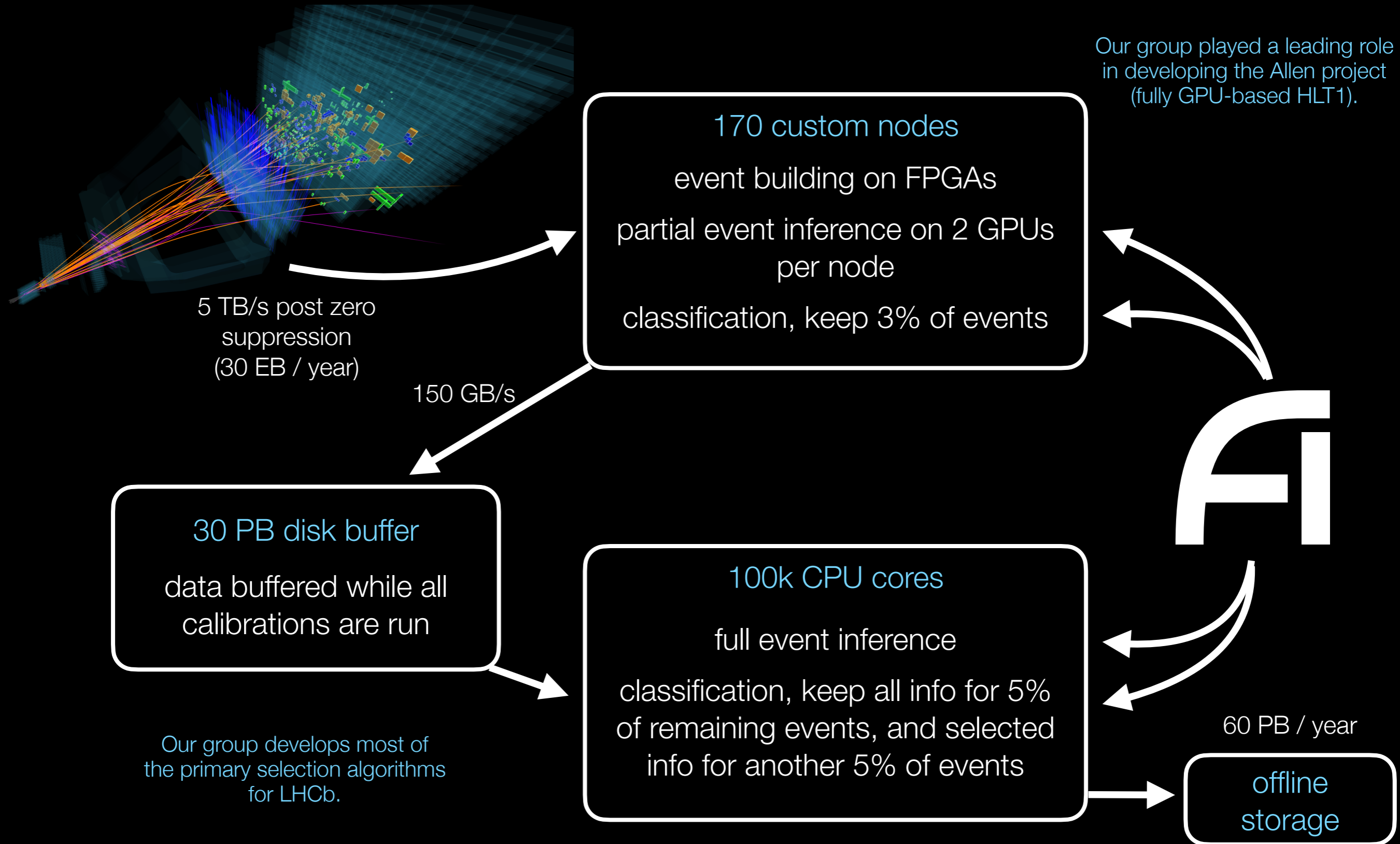

Real-Time Data Processing @ LHCb

Dark-Sector Physics

dark quarks?
dark forces?
dark higgs?
dark leptons?

Robust & Interpretabile AI / AI for Scientific Discovery

Real-Time Calibration & Analysis

Our group played a leading role in developing the Allen project (fully GPU-based HLT1).

170 custom nodes

event building on FPGAs

partial event inference on 2 GPUs per node

classification, keep 3% of events

5 TB/s post zero suppression
(30 EB / year)

150 GB/s

30 PB disk buffer

data buffered while all calibrations are run

Our group develops most of the primary selection algorithms for LHCb.

100k CPU cores

full event inference

classification, keep all info for 5% of remaining events, and selected info for another 5% of events

60 PB / year

offline storage

We developed a novel neural network architecture that guarantees robustness and monotonicity (NeurIPS), which has been adopted for all major classification tasks. We also showed that our LHCb tech beats SOTA performance in medicine, criminal justice, finance, etc. [ICLR 2023]
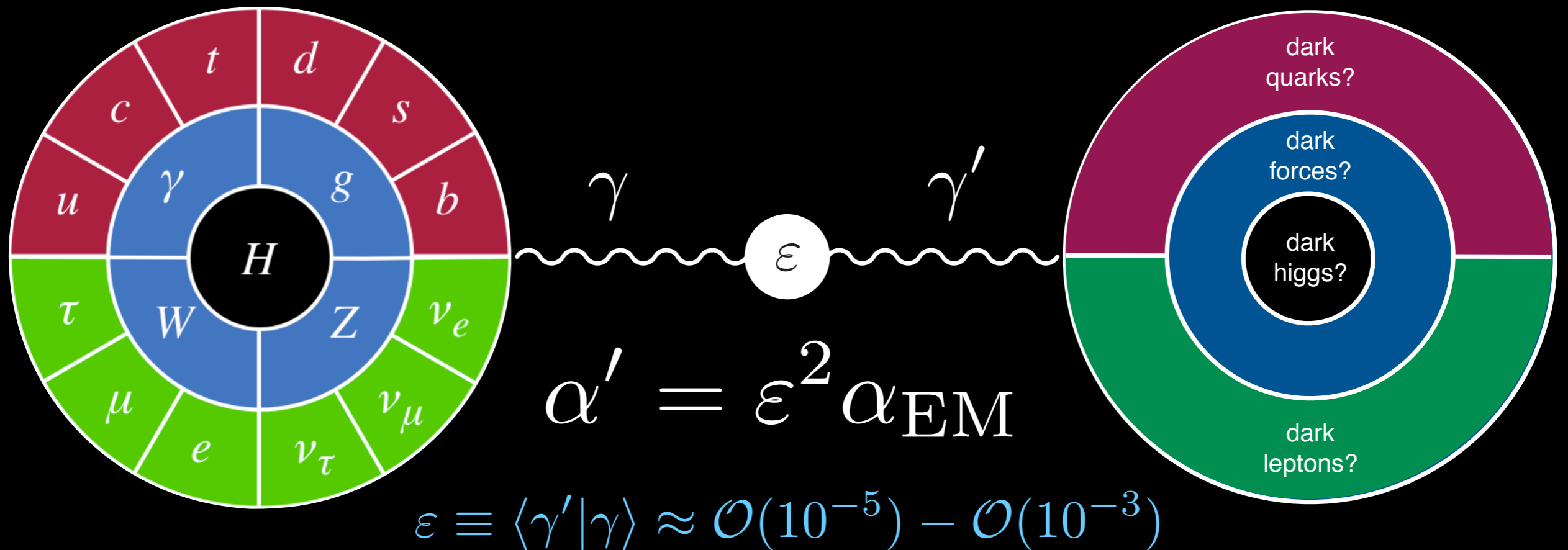
Weakly Interacting Massive Particles (WIMPs)

WIMP Miracle: If DM particles have EW-scale masses and interactions, and were in thermal equilibrium with SM particles in the early universe, the predicted relic DM density agrees with the observed value in the universe today.
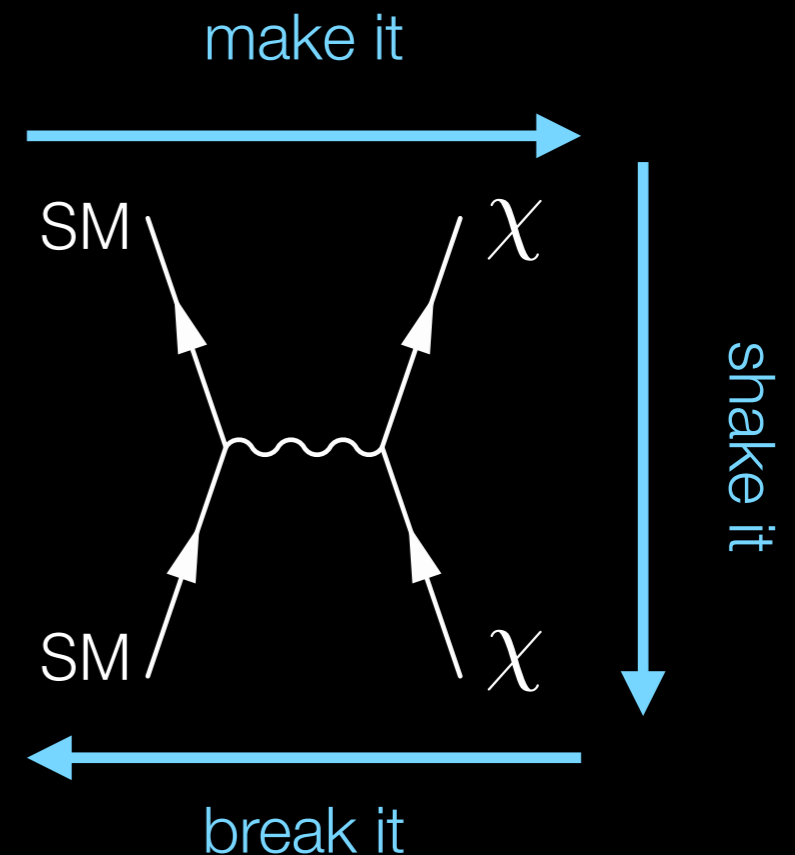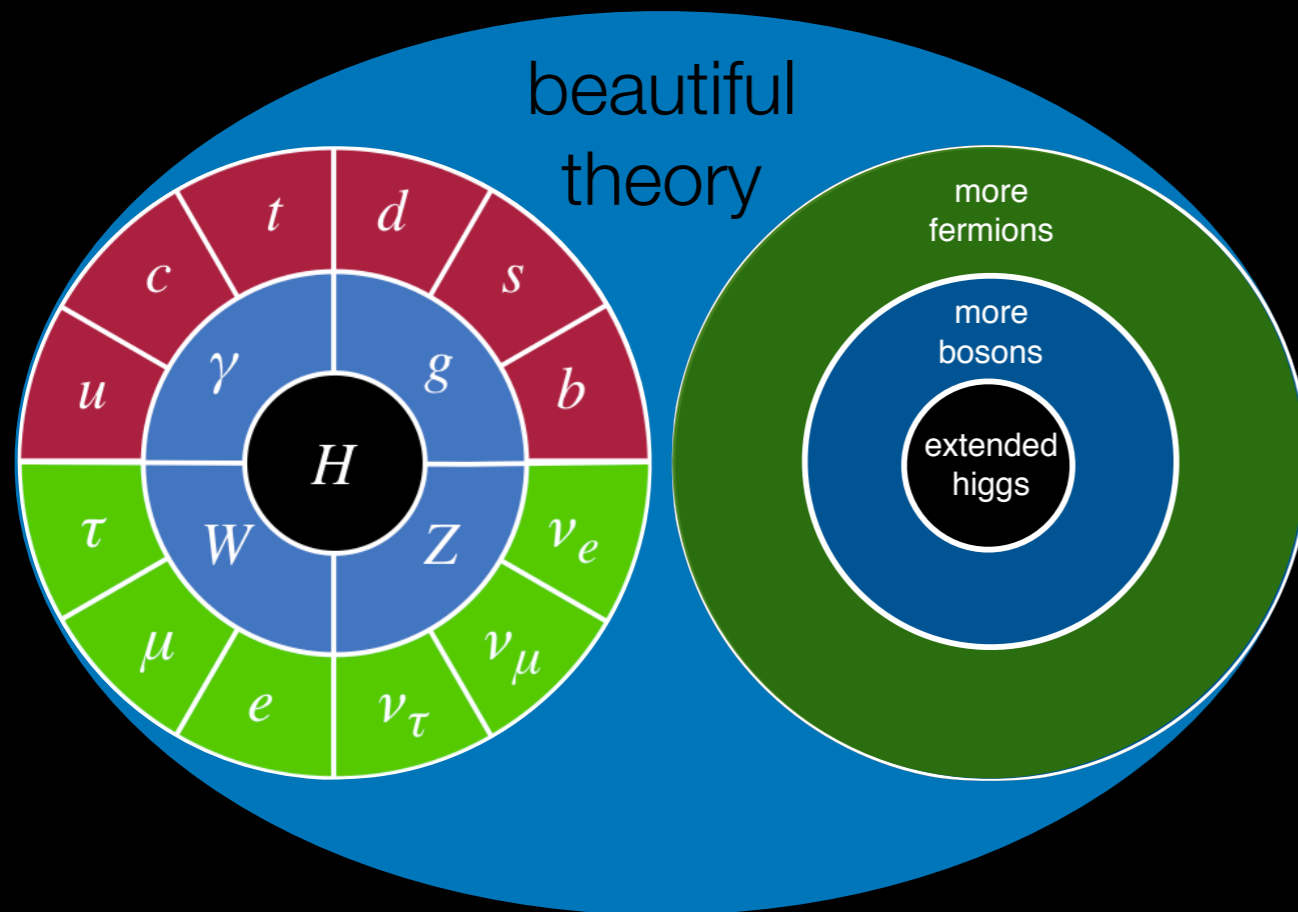
Strong constraints on WIMPs up to O(TeV) from production searches at the LHC, and from both direct and indirect dark matter searches.

Hidden (Dark) Sectors

What if there is no connection between the SM and dark sector up to the Planck scale?
(Hidden sectors can result from a Grand Unified Theory (GUT) of nature, and are generic in string theory constructions.)

$$\gamma \qquad \varepsilon \qquad \gamma'$$

$$\alpha' = \varepsilon^2 \alpha_{\rm EM}$$

$$\varepsilon \equiv \langle \gamma' | \gamma \rangle \approx \mathcal{O}(10^{-5}) - \mathcal{O}(10^{-3})$$
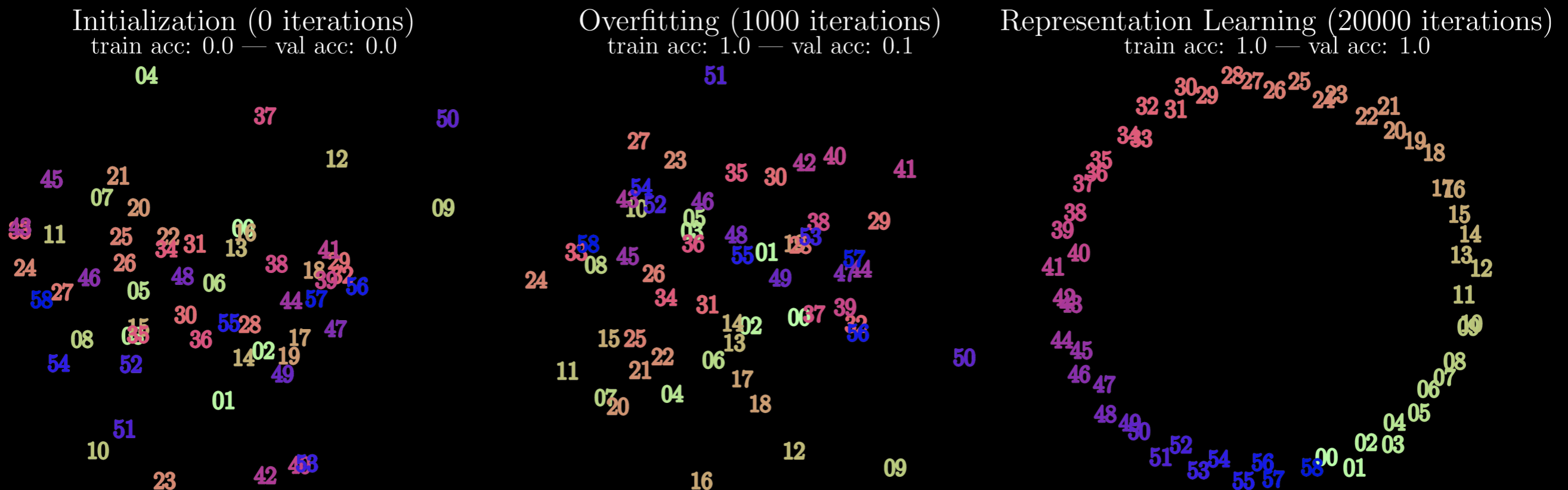
lightest DM particle could be
stable because it's (dark) charged

As long as the sectors are connected at some scale (e.g. if they are both part of a GUT), then quantum mechanical mixing between the photon and dark photon is unavoidable. We can make it in the lab, and it can decay into SM particles that we can detect.

Deep Learning + Deep Thinking ➤ Deep Understanding

In simple problems, e.g. algorithmic ones, AI may seem to do very strange things, but in some cases we have been able to use physical reasoning to not only gain qualitative understanding, but to also develop theories that can quantitatively describe the learning dynamics.

Liu, Kitouni, Nolte, Michaud, Tegmark, MW [Oral Highlight @ NeurIPS 2022, 2205.10343]

Initialization (0 iterations)
train acc: 0.0 — val acc: 0.0

Overfitting (1000 iterations)
train acc: 1.0 — val acc: 0.1

Representation Learning (20000 iterations)
train acc: 1.0 — val acc: 1.0

Applying this same idea to nuclear data tables — the machine learns the Shell Model and Pauli Exclusion Principle on its own! This may be a novel approach to the scientific method itself.

Summary & Messages

- PhD projects typically involve at least 2 of the following components: work on the real-time data-processing system, at least one (often more) data analyses leading to publications, an AI-based project, and a phenomenology/theory project (or multiple of these). (There is a lot of freedom in determining what goes into your PhD.)

- Our group is a leader in the Real-Time Analysis (RTA, formerly Trigger) Project.

- We work in small collaborations on projects with excellent visibility and very high impact.

- I am the Deputy Director of the IAIFI. Many LHCb group members are also in the IAIFI and spend considerable time working on AI projects.

- Our past students have been successful in moving into the careers they wanted (both academia and data-science industry).

- Good luck with your decision! (No matter what you decide, it will almost certainly work out well.)

- Please come to the IAIFI / PhD in Physics, Statistics, & Data Science session later today!